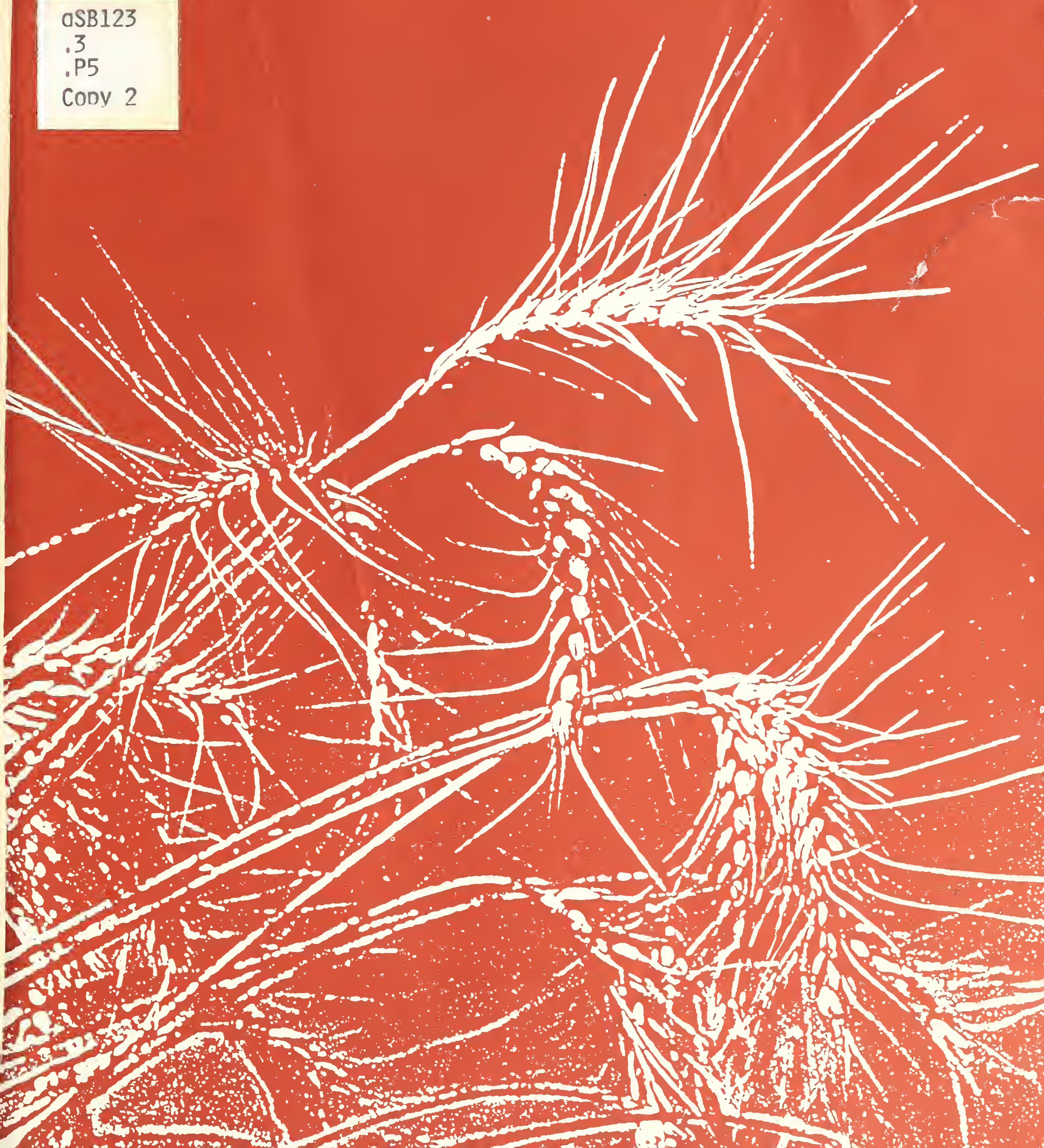
United States
Department of
Agriculture

Prepared by
National Plant Genetic
Resources Board

Plant Germplasm

Conservation and Use



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This document is dedicated to the memory of Clarence O. Grogan, who served as Executive Secretary of the National Plant Genetic Resources Board from 1979 until his untimely death October 30, 1983.

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H. Grant Vest, Jr., Department of Horticultural Sciences, Texas A&M University, College Station, TX

Wilson H. Foote, Agricultural Experiment Station, Oregon State University, Corvallis, OR (ex officio member)

* * *

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NATIONAL PLANT GENETIC RESOURCES BOARD

The National Plant Genetic Resources Board (NPGRB) was initially appointed by the Secretary of Agriculture in 1975. The task of the Board is to advise on policies related to the collection, description, maintenance, evaluation, and effective utilization of the living resources represented by crop cultivars and primitive and wild forms of our Nation's crops. These resources are necessary for scientists to have the genetic variability needed to maintain and enhance the productivity of U.S. agriculture for the present and future.

The objectives of the NPGRB are (1) to advise the Secretary of Agriculture and officers of the National Association of State Universities and Land Grant Colleges of national plant germplasm needs and (2) to identify high-priority programs for conserving and utilizing plant genetic resources, including the collection, maintenance, description, evaluation, and utilization of genetic stocks in plant improvement programs.

The duties of the NPGRB are (1) to inform themselves of domestic and international activities directed to minimize genetic vulnerability of crops; (2) to formulate recommended actions and policies on collection, maintenance, evaluation, and utilization of plant genetic resources; (3) to recommend actions to coordinate the plant genetic resources plans of domestic and international organizations; (4) to recommend policies to improve plant quarantine and pest monitoring activities that relate to plant germplasm exchange and distribution; and (5) to advise on new and innovative approaches to plant improvement.

Members of the Board are appointed by the Secretary of Agriculture. The Board, which usually meets twice each year, is composed of individuals with diverse capabilities and distinguished by their knowledge and interest in plant genetic resources management.

The Assistant Secretary for Science and Education is Chairman, and a Vice Chairman is appointed from the membership. The Executive Secretary is provided by the Assistant Secretary's office. The Board reports to the Secretary of Agriculture through the Assistant Secretary for Science and Education, who provides financial and personnel support for the operations of the Board.

Regulations for Federal advisory committees mandate that the Board terminate 2 years from the date of each renewal. In the event the Board tenure is over a period of years, partial rotation of the Board membership should be practiced every 2 years to provide for continuity and broad representation on the Board. The Secretary of Agriculture would like (1) to ensure continuity and increased involvement of the Board in

genetic resources planning and coordination activities, (2) to increase the association of the activities of the Board with genetic resource programs of State and private industry research organizations, and (3) to expand the scope of the Board to relate to other kinds of plant genetic resources of interest to agriculture.

The NPGRB was a direct outgrowth of the alarm caused by the southern corn leaf blight which spread swiftly over the U.S. corn crop in 1969 and 1970 and reduced yields by 50 percent in some States and an estimated 15 percent nationwide. The southern corn leaf blight was not the first plant disease epidemic to strike an important crop, but it was the first to shock the Nation into the realization that many of our major crops rest on a narrow genetic base and, consequently, are highly vulnerable to attack by new forms of disease and insect pests. It also resulted in a series of studies designed to establish strategies to reduce the probability of future epidemics and how best to cope with them should they occur. This among others are concerns addressed by the NPGRB since 1975. The accompanying document developed by the NPGRB describes an eight-phase program for minimizing genetic vulnerability that would make possible the proper conservation and utilization of the vast reservoir of plant germplasm.

SUMMARY

- Most food, feed, fuel, and fiber crops produced in the United States today were developed from plants introduced into this country by the earliest settlers and, in more recent times, by plant explorers.

- The United States has a long history of plant introduction, which evolved through various stages, beginning with American consuls overseas who sent back seeds of useful plants. The present National Plant Germplasm System (NPGS) is a coordinated network of institutions and agencies (State, Federal, and private) working cooperatively to introduce, maintain, evaluate, catalog, improve, distribute, and use plant germplasm.

- The success of modern crop cultivars, the explosion of the world population, and the disturbance to ecosystems by the industrial revolution have tended to reduce the amount of genetic variability in agricultural plants.

- Improvement of crop cultivars through plant breeding was a major catalyst of the agricultural revolution of this century. Breeding for higher yield; resistance to insects, diseases, and environmental stresses; better nutrition; safer and higher quality food; and biomass production demand a well-planned system for the conservation, maintenance, and utilization of a wide assortment of plant genetic resources. Such a system is crucial to the future well-being of this country, and the central responsibility for it must rest squarely with the U.S. Department of Agriculture (USDA).

- "Genetic vulnerability" of plants is a term used to describe situations that can lead to epidemic (epiphytotic) losses, and no program can reduce the probability of such losses to zero. The best approach to lowering the probability or solving the problem, should one arise, is to have a sound program of research and development activities for conserving and using plant genetic resources. The program includes plant introduction, classification, evaluation, genetics and cytogenetics, genetic engineering including cell culture and protoplast fusion, developmental research, biochemistry, physiology, applied research, production of seeds and plant parts of improved varieties for use by farmers, and, finally, the use of these varieties in agriculture.

- This program represents an outstanding example of State, Federal, and private industry cooperation and planning. Plant germplasm resources and their use are central to a multitude of national goals, including increasing exports; boosting farm income and enhancing the national economy; protecting the environment; conserving energy; promoting soil conservation; minimizing cost of food; providing safe, high-quality, and nutritious food; improving the feeding efficiency of grain and forage crops; developing pest-resistant crops and crops better adapted to less favorable environments; and minimizing costs of building materials and other forest products.

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ABBREVIATIONS

ARS - Agricultural Research Service

CAC - Crop Advisory Committees

CSRS - Cooperative State Research Service

IBPGR - International Board for Plant Genetic Resources

NPGRB - National Plant Genetic Resources Board

NPGC - National Plant Germplasm Committee

NPGS - National Plant Germplasm System

NSSL - National Seed Storage Laboratory

RPIS - Regional Plant Introduction Stations

SAES - State Agricultural Experiment Stations

USDA - United States Department of Agriculture

Plant Germplasm

Conservation and Use

INTRODUCTION

Lack of Native Crops in the United States

If American consumers were asked to live on food from crops native to the United States, they would probably be shocked that their diet would be limited to sunflower seeds, cranberries, blueberries, strawberries, pecans, and not much else. Bread, cereals, potatoes, most fruits, and vegetables would be missing from their tables. Tobacco would be available, but they would have no cotton or flax textiles for clothing and linens. If the United States had to import the food we eat and fiber used to clothe us, the balance of payments for oil would look small by comparison. Fortunately, we do not import food and fiber directly; however, resources that support our domestic food and fiber production are imported.

Without the systematic use of germplasm resources, the average acre yield of corn, for example, could not have risen 333 percent from 1930 to 1980. Moreover, the energy required to produce the 1980 corn crop would have increased oil imports by millions of barrels if the yield per acre had remained at the 1930 level since several million more acres would have been required.

History of Plant Introduction

In precolonial and colonial days, early settlers of the area now known as the United States found few of the crops they had known in the Old World. The Indians grew some corn, beans, and squash; however, these crops had been brought into this area much earlier by Indian tribes from what is now Mexico.

In the early settlement days, immigrants to the United States quickly learned that they had better bring seed with them. The U.S. Government early recognized this paucity of seed and encouraged the search for seed of adaptable crops. In 1819, American consuls overseas were asked to collect seed of useful plants and send them to the United States. From 1836 to 1862, the U.S. Patent Commissioner administered the introduction of plants. The U.S. Department of Agriculture (USDA) was established in 1862. Since that time various agencies of USDA have conducted plant exploration and plant introduction activities.

The Current Challenge for Food, Feed, Fuel, and Fiber

The United States and the world face many agricultural challenges now and in the future. During the past 60 years the population of the world has grown from 1 billion plus to at least 4 billion. It has been predicted that the population may reach 6 to 8 billion by the end of this century.

Studies have shown that, if the human family expects to feed its burgeoning numbers, the present supply of food will have to be doubled. In addition to this humanitarian aspect, bountiful and secure agricultural production is essential for the welfare and economic prosperity of nations.

Before the dawn of recorded history, people began to become less dependent on hunting and foraging by turning to the cultivation of plants. Throughout the centuries, plants judged to be superior were saved for propagating subsequent crops, some of which were doubtlessly chance or manmade hybrids. Thus, a vast number of local varieties or land races were developed in all parts of the world. Great genetic variability existed within and among these varieties. Moreover, species not chosen for cultivation generally survived in nature because the pressure of the human population and advanced agricultural technology had not yet destroyed their natural habitats.

Professional plant breeding began around the turn of this century with the rediscovery of Mendel's laws and the development of the chromosome theory of heredity. By applying these scientific principles, breeders developed modern crop cultivars that were generally highly uniform and specialized for yield, quality, and adaptation to specific environments. The constant release of improved varieties and the adoption of advanced production technologies resulted in remarkable increases in agricultural productivity. The superiority of these modern cultivars over folk (land race) varieties led to their widescale adoption in this country and in other parts of the world. Many old varieties were abandoned and lost. Plant genetic resources in the wild as well as those in cultivation as folk varieties continue to disappear.

Responsible agricultural leaders in this country and abroad have recognized for many years that plant genetic resources were being lost and that genetic variability among varieties was being reduced. The urgency of the southern corn leaf blight epidemic of 1970 shocked the United States into considering the conservation and proper use of plant genetic resources as activities vital to the Nation's continued well-being.

Tragic epiphytotics have occurred since Biblical times. Recent examples are the Irish potato famine of the 1840's, the Ceylon coffee rust in 1870, the United States wheat rust in 1916, and Bengal rice problems in 1942. The destruction of chestnuts several years ago and the attack by the pathogen causing Dutch elm disease add to the list. Droughts in India, Australia, Africa, and our Midwest and Far West in recent years emphasize that crops are extremely vulnerable to stresses.

The term "genetic vulnerability" was coined to explain the situation leading to the serious outbreak of southern corn leaf blight in 1970. Uniformity is the key factor in the genetic vulnerability of crops. The probability of an epiphytotic is increased when large numbers of plants are genetically alike. If one plant is susceptible, all are susceptible.

Although genetic diversity offers some protection against the outbreaks of pests, it does not guarantee that they will not occur. Producers and consumers want improved cultivars with high yields, good quality, and uniformity of product. They want cultivars that lend themselves to low production costs.

Modern mechanized farming requires uniformity of seeds, maturity, and plant morphology. Genetic diversity is sacrificed because everyone wants to grow the best cultivar. Farmers want to grow the cultivar that gives them the best return on their investment. Seedsmen and breeders want to breed and provide seed of the best cultivar to their customers and in so doing enhance their position in the market place. Breeders tend to use the better cultivars as breeding stocks for further advances, with a consequent reduction in genetic variability.

Plant breeders now tend to release cultivars with greater genetic diversity than they did formerly when the "pure line" theory was more in vogue. This trend helps to reduce vulnerability. However, genetic diversity within cultivars, by itself, will not adequately minimize the risks. Having access to numerous cultivars is another way to reduce genetic vulnerability, which may be minimized most effectively by a sound research program in each phase of the program described in this document. Thus, genetic vulnerability is not simply uniformity in the fields; it is related to such factors as our ability to respond quickly to unexpected conditions. This ability to respond is related to knowledge of the crops involved and their relationships to pests and physiological stresses.

Role of Plant Genetic Resources in Agriculture

Crop production can be improved (1) by improving the genotypes of the plants and (2) by improving the environment through cultural practices and nonheritable protection from pests, both of which normally must occur simultaneously. All knowledge and practices must be channeled into these two mutually dependent avenues or they cannot influence production. Plant genetic resources are used in plant breeding to improve genotypes and thereby sustain and improve crop productivity.

Plant genetic resources extend from wild or exotic species to cultivars commonly grown by farmers. A program in agricultural research connects these extreme types of plant genetic resources. Because this work is scattered geographically, involves all crops and many different disciplines, and is shared by State and Federal agencies and industry, it is easy to underestimate the significance of the total program. The capability for the United States to carry out this work demands that the technical competence required in all areas of germplasm biology be assessed and that necessary steps be taken to

ensure its availability. Genetic improvement of crops requires that plant genetic resources be collected, maintained, evaluated, and used.

The sequences or phases from collecting germplasm to its use by farmers may best be thought of as a continuum that establishes a gene flow from the germplasm source to the cultivars used by the consumer. Unless all phases are operating, an imbalance or block develops. A continuous flow keeps high-yielding cultivars on the market, improves the quality of agricultural products, reduces dependence on pesticides, minimizes cost of production, and reduces vulnerability to pests and environmental stresses.

Society is concerned about the loss of species from the earth. The Endangered Species Act of 1973 was passed to minimize this loss. The Nature Conservancy and other organizations are active in protecting life forms in preserves, zoos, and arboreta and in preventing environmental disturbances that may endanger the habitat of species. This is conservation at the species level. Many endangered species have no apparent use except that they are a part of the great interdependence of life forms in ecosystems. The disappearance of a species might cause an ecological shift unfavorable to esthetic values or resource use.

The NPGRB contends that society should be equally concerned about the conservation of the genetic variability accumulated within species during the long evolutionary processes. After all, most of these species have demonstrated their economic usefulness since the dawn of agriculture. People depend on them for food, fiber, and industrial materials to survive and to enhance the quality of life. We will continue to encounter changing pest problems, changing concepts and needs in food safety and human nutrition, growth in population, the need to grow crops in more environmentally stressed situations, and the increased use of plants as biomass for energy.

Basic plant genetic resources exist in four ways: (1) in natural ecosystems according to the "survival of the fittest" principle with no inventory and no managed preservation scheme; (2) as local varieties cultivated by small-scale farmers in lesser developed countries where modern cultivars do not dominate the agriculture; (3) as collections and materials assembled by private corporations, professional research scientists, private collectors, hobbyists, and amateurs; and (4) as permanent collections maintained in the public interest by governments.

Early in its history, the United States decided that the first three maintenance categories did not have the long-term continuity and stability to provide plant resources of cultivated crop species. The fourth form for maintaining plant genetic resources in a national scheme is an integral part of the NPGS. This component of the system has evolved over time, particularly since the Research and Marketing Act of 1946 established regional and interregional plant introduction stations with joint Federal and State funding.

Phase 1

Collect, maintain, evaluate, document, and distribute plant genetic resources.

This phase is essential to the full utilization of germplasm and has received substantial attention by the Agricultural Research Service (ARS) and State agricultural experiment stations (SAES) in recent years.

It helps to provide the Nation with the plant genetic resources to meet current and future needs. The high priority assigned to this work was stimulated in part by not only national interests but also worldwide recognition of the need for germplasm resources as expressed by the International Board for Plant Genetic Resources (IBPGR). IBPGR was established to assist national and international programs with their needs and has established realistic guidelines for genetic resource management. The NPGRB surveyed the status of germplasm collections in 10 crops and found deficiencies in existing collections, inadequate support for curators of germplasm, and inadequate training of personnel with skills and interest in germplasm biology. An analysis of other crops would reveal similar deficiencies.

The NPGS now maintains over 400,000 accessions of germplasm representing several hundred crop species. New accessions are added to the collection at the rate of 7,000 to 15,000 per year. Most of the new accessions come through exchanges with other countries, fostered in large part by cooperative efforts of the IBPGR. However, overseas and domestic plant explorations still play an important part in the collection program and are coordinated by the USDA Plant Exploration and Taxonomy Laboratory in Beltsville, Maryland. New accessions are turned over to the Regional Plant Introduction Stations (RPIS), curators of special collections, or national clonal repositories for the establishment of base and working collections.

Working collections involve maintenance, evaluation, documentation, and distribution of the many thousands of accessions. Each RPIS (Northeastern at Geneva, New York; Southern at Experiment, Georgia; North Central at Ames, Iowa; and Western at Pullman, Washington) is assigned certain field and horticultural crops adapted to that region. Other major collections include the USDA Small Grain Collection, the Soybean Collection, the Potato Collection, and the clonal repositories for fruit, nut, and special crops. In addition, special curators handle genetic and cytological stocks of maize, barley, wheat, and other crops with support from SAES, ARS, and the Cooperative State Research Service (CSRS). All these working collections provide distributions of accessions to plant breeders, geneticists, and other interested plant scientists not only in this country but throughout the world.

Long-term storage of valuable seed accessions for most of our important crops is provided by the National Seed Storage Laboratory (NSSL) at Fort Collins, Colorado. This laboratory also conducts research on storage conditions and serves as a base collection in support of international germplasm resource centers.

Overall coordination of the vast NPGS is provided by the National Plant Germplasm Committee (NPGC) which consists of USDA, SAES, and private industry scientists with germplasm interests. All three groups play a vital role in conserving and utilizing our plant genetic resources.

Phase 2

Understand the genetic variability and geographic distribution of cultivated species, and their taxonomic and cytological relationships with closely related species.

Knowledge of the genetic structure of cultivated plants and of their genetic relationships with closely related species is essential for effective planning and execution of plant improvement programs. Concepts of interspecific relationships are developed from basic studies in many disciplines: genetics, cytogenetics, biochemistry, morphology, ecology, and biogeography. Such information is required for the sound and workable taxonomic requirements needed to catalog and use the large number of accessions in germplasm collections. More important, this information is needed by breeders in transferring desirable characteristics to new crop varieties.

Genetics.--In the study of the genetic architecture of crop plant species, linkage groups are mapped for the most clearly expressed marker genes. The modes of inheritance of quantitative and cytoplasmically determined characters also are investigated. The methods exploit both spontaneous and artificially induced mutations. Genetic studies promote an understanding of the basic genetic makeup of a plant species and provide genetic lines that have immense potential for solving problems in plant physiology, morphological development, and plant biochemistry. These investigations are coordinated with studies of the inheritance of economic traits visualized in phase 4 and inevitably are integrated with those of cytogenetics.

Exotic accessions also are studied to determine their crossability with crop species and the characteristics of hybrids that might thereby be produced. These investigations determine the limits of hybridization, the nature of barriers to genetic exchange, fertility and viability of hybrids and their advanced generations, and the extent of genetic and cytoplasmic differ-

ences between the parents. Not only is such information vital to biosystematists, but it also informs the plant breeder of the feasibility of using such accessions successfully.

Cytogenetics.--Genetic analysis of a species is aided by coordinating it with the study of chromosomes and gene behavior. The chromosomal composition of a species often is analyzed by studying cytological deviations from normal. Wild forms of the cultivated species and related species are routinely analyzed for chromosome number and morphology as aids in understanding natural relationships and the nature of barriers to gene exchange between taxa. Studies of the relationship between meiotic chromosome pairing and fertility in diploid and polyploid hybrids often clarify the nature of hybrid sterility and lead the way to the most efficient use of exotic germplasm.

Development and maintenance of genetic and cytogenetic special stock collections from economically important crop species are necessary for progress in research. The special stocks also are used in physiological and biochemical studies that are concerned with an understanding of plant growth and developmental processes. Genetic stock collections are uniquely useful as research tools and are not to be confused with the general germplasm collections that provide genetic variability for crop improvement. Support of genetic stock centers for crop species comes from SAES, ARS, and CSRS.

Biochemistry.--The literature contains many examples of the use of biochemical constituents for studies of the classification and evolution of plant species. For example, differences in terpene content are of systematic interest in the pines as are differences in storage proteins in the legumes. Besides aiding systematists, such determinations may reveal new sources of compounds with nutritional or industrial significance. The degree and pattern of variability of isozymes permit identification of genotypes and the analysis of interspecific and subspecific relationships. The nature of pest resistance, food safety, and nutritional quality also can be determined through classical as well as molecular and biochemical methods.

Morphology.--Morphological traits furnish the data for classical taxonomy and often provide the criteria for classification of herbarium specimens and for field identifications. Qualitative traits are observed and quantitative traits are measured in the form of the whole plant or its parts. In plant germplasm assemblages, the collection of such data is usually limited to traits of systematic and economic importance, but studies integrating morphology with genetics are mutually beneficial.

Ecology.--The distribution of a plant taxon is determined by its ecological requirements. Reproductive isolation can play an important role in evolution and thus be of interest to systematists. Observations of the responses of plants to temperature, light intensity, photoperiod, soil type, and other factors in their native habitats and in trial plantings can give important information for the collection and effective use of plant germplasm resources.

Biogeography.--Information concerning geographic distribution often directs collectors to critical areas and helps to distinguish between wild and domesticated forms and the area of cultivation beyond the native range. Such differences can be significant in relation to the presence or absence of pests. Geographic isolation frequently expedites the differentiation of new biotypes and thus can provide plant explorers with genetic variants that may be useful to plant breeders in plant collecting expeditions. Weedy races may accompany the cultivated forms and play a significant role in the evolution and use of plant species.

Continued research studies in these areas provide the following benefits: (1) Identify the nature of genetic control of certain characteristics of interest to plant breeders; (2) reveal the opportunities and limitations of gene transfers from accessions to acceptable cultivars; (3) identify characteristics not presently available in crop cultivars; (4) ascertain the origin and sites of domestication; and (5) establish evolutionary relationships among domesticated and wild species and thereby contribute to plant taxonomy.

Phase 3

Evaluate plant genetic resources for specific desirable traits.

As plant genetic resources are collected or produced, they must be evaluated to determine those traits they possess that are useful for plant improvement. As traits are identified, the germplasm is used as parental material for developing new genetic complexes. When crosses are made between strains of divergent origin, the first generation may exhibit hybrid vigor and the subsequent generations of such hybrids display genetic variability resulting from the recombination of genetic material in new and unique genotypes. This provides further opportunity for the isolation of more efficient and desirable types.

Evaluation is done primarily by the users rather than by the maintainers of the plant genetic resources. The potential value of germplasm collections depends upon the efficiency of techniques designed to characterize the genetic differences among the individual items of a collection.

Ideally, indepth evaluation should be done by crop improvement teams made up of breeders, entomologists, pathologists, agronomists, biochemists, and other scientists interested in plant genetics and production. Because of close ties with farmers, such a team would be aware of problems arising from an outbreak of a new pathogen or race or a new destructive insect. They would identify the causal agent involved and establish either the suitability of existing techniques for evaluating plant reaction or, if necessary, devise and evaluate new procedures. Such teams should have the field and laboratory facilities and the crop expertise necessary for success. The procedures necessary in any search for resistance also are likely to be required in the transfer of such resistance to commercially useful cultivars.

This team approach has a long history of success in discovering sources of resistance to pathogens such as downy mildew in corn, corn viruses, several smuts and rusts of small grains, late blight in potatoes, and the spotted alfalfa aphid. Within the past 40 to 50 years the improvements in pest resistance of our major cultivated crops have been an important factor in increasing efficiency of our agricultural production.

Germplasm is evaluated for attributes other than disease or insect resistance. Examples of such attributes are morphological variations contributing to increased yield; variation in quantity and quality of proteins, amino acids, or fats; the presence or absence of toxic substances, such as trypsin inhibitor in soybeans; soluble solids in tomatoes; and tenderness in sweet corn. Such a list could be greatly extended. Evaluations for desirable attributes of the type listed may require specialized equipment and specifically trained personnel. Fortunately, instruments and methodology are available for measuring many attributes of interest. Not all procedures, however, have the capability or flexibility for handling the large numbers of plants required for evaluating large plant germplasm collections.

Phase 4

Study the genetic mechanisms controlling the inheritance of important traits.

The discovery of desirable traits in the evaluation phase is the first step in the use of the germplasm resource. Then it must be determined if a trait is heritable and expressed in the progeny. The nature of the genetic control can then be studied to assist the breeder in using the trait. Often it is important to know whether a new source of germplasm has genes the same as or different from those in crop cultivars already in use.

Breeders and geneticists are urged to consider various problems for research identified by soil scientists, nematologists, pathologists, entomologists, and physiologists as well as farmers, food scientists, trade associations, processors, and consumers. Breeders face a wide array of potential parental materials, and the profession of plant breeding offers many breeding methods. If a good choice of objectives, materials, and methods is to be adopted, information is needed on the inheritance and genetic variability of desirable traits.

Phase 5 **Combine genes from diverse sources into improved germplasm more useful to plant breeders.**

Genes for desirable traits or characteristics often are found in stocks unsuitable for cultivation. Resistance to pests, ability to withstand cold or drought, high protein content, improved amino acid balance, early maturity, and a host of other desirable features seldom are found together in one source as an ensemble of the characteristics required for successful cultivation of crops. Competitive cultivars must have a composite of characteristics that makes them more profitable to grow than those already on the market. Building insect and disease resistance into superior cultivars requires long-term, continuous work by competent entomologists, pathologists, and breeders. This work connects germplasm collection, evaluation, and genetic analysis with applied breeding. From a large number of objectives that might be pursued, those that have a high probability of success are identified. It allows the more applied programs to direct their limited resources and time to efforts where more immediate success is required and where all aspects of plant improvement and productivity are considered.

The work of the first four phases produces breeding materials that possess unique characteristics or unique combinations of genes with reasonably good agronomic or horticultural features. In this phase improved germplasm is developed which is ready for further development into crop cultivars. It is becoming more and more common for Federal and State agencies to release improved breeding stocks so that applied breeders from a public or private organization or a lesser developed country may use the material at this stage.

Adaptation, or its lack, becomes an important problem in the transfer of desired traits from an exotic or wild strain to a commercially useful cultivar. Even though the genetic basis of the desired trait may be simple, the combination of specific characteristics with all other genetic traits affecting adaptation and field performance may result from a very complicated genetic system. The degree of complexity often varies with the

degree of dissimilarity of the parents used. Again, it appears that germplasm enhancement as well as evaluation can best be accomplished by a crop-improvement team. In this phase the recurrent evaluation of resource material being advanced toward commercial utilization becomes of utmost importance.

Evaluation of the relative merits of candidate strains and cultivars is often done by a series of replicated performance trials over a period of years at several locations. The material is subjected to a sample of the environments that future cultivars are most likely to encounter. This includes variation in soil type, nutrition levels, diseases, pests, weather, cultural practices, and harvesting methods. Although this type of field evaluation is still the best predictor of the future performance of any new cultivar, scientists often resort to evaluations in controlled environmental conditions. This is done to obviate the tremendous variation in weather and infestations that nature provides. For example, estimates of disease resistance often are more reliable from artificial inoculations than from natural field conditions. Cold tolerance may be investigated in field plots with several planting dates or treatments or even in a temperature-controlled greenhouse or growth chamber.

Phase 6 **Breed, release, and maintain improved germplasm and cultivars.**

The germplasm resource base for any crop involves a diverse assemblage of materials that may be roughly grouped as follows: (1) Currently useful cultivars, (2) the very sizable reservoir of adapted but not currently utilized materials, (3) exotic and usually unadapted materials, and (4) the wild and weedy relatives. The problems relating to the use of these types of germplasm in breeding increase in complexity with this progression. Plant breeding progress is most readily achieved when efforts can be confined to materials in groups (1) and (2). Necessity, however, may require the use of materials from groups (3) and (4).

Cultivars are improved through a system of germplasm resource management. However, the majority of plant breeding experience and its foundation in quantitative genetic theory are based on studies with cultivars and other adapted materials. The use of exotic and wild material poses a number of special problems for which neither theoretical nor practical answers are adequate. If we are to move to an activity that recognizes vigorous utilization, however, adequate continuing support must be provided for crop improvement.

Crop yields in the United States have increased dramatically in the past 50 years. The following table shows the average

Average yield of specified field and horticultural crops, 1930 and 1980

Crop	1930 Acre yield	1930 Kg/ha	1980 Acre yield	1980 Kg/ha	Percent increase
Barley	24 bu	1,290	50 bu	2,688	108
Corn (maize)	21 bu	1,317	91 bu	5,708	333
Grain sorghum	11 bu	690	46 bu	2,885	318
Oats	32 bu	1,147	53 bu	1,900	66
Rice	47 bu	2,369	98 bu	4,939	109
Rye	12 bu	753	24 bu	1,505	100
Soybeans	13 bu	874	26 bu	1,747	100
Wheat	14 bu	941	33 bu	2,218	136
Peanuts	650 lb	728	1,645 lb	1,842	153
Tobacco	776 lb	869	1,940 lb	2,173	150
Cotton	157 lb	176	404 lb	452	157
Alfalfa	1 ton	4,480	3 tons	6,720	50
Sugarbeets	12 tons	26,880	20 tons	44,800	67
Sugarcane	16 tons	35,840	37 tons	82,880	131
Lettuce	80 cwt	8,960	261 cwt	29,232	226
Onions	159 cwt	17,808	296 cwt	33,152	86
Potatoes	66 cwt	7,392	262 cwt	29,344	297
Tomatoes:					
(Fresh market)	61 cwt	6,832	201 cwt	22,512	230
(Processing)	4 tons	8,960	24 tons	53,760	500
Citrus	6 tons	13,440	13 tons	29,120	117

yields of some field and horticultural crops, as recorded in USDA's Agricultural Statistics for 1930 and 1980. The percentage increases from the original values range from 50 to 500 percent or about 1 to 8 percent per year on the average. A graph of average annual yields for each crop would have many ups and downs, influenced primarily by the weather. Nevertheless, the trend has been steadily upward. Some crop yields are apparently beginning to plateau. Consumer demands and economic pressure require that we acheive equivalent or better gains in the next 50 years. Increased research on the biological processes of plants and plant pests is required to put genetically superior crops in the field and protect them against pests and environmental stresses.

Many factors influence the yield of a modern crop cultivar. The proper integration of genetic potential with insect and disease control, weed control, intelligent use of fertilizer and irrigation, timely and efficient cultivation and harvest, soil conservation practices, and other management activities are essential to continued yield increases. As crop production systems increase in complexity, genetic yield potential must

keep pace. However, the genetic diversity also must be broad enough to avoid losses from pest outbreaks and to minimize the effects of annual weather fluctuations.

Phase 7 **Produce high-quality seed and plants for distribution to farmers.**

This phase of germplasm resources management has become increasingly a function of the commercial seed and nursery industry. The function of the seed trade is to supply farmers with an uninterrupted source of improved, high-quality seed. Some segments of the industry also support extensive breeding programs and thereby contribute primarily to the objectives outlined under phases 5 and 6. However, the industry is not in a position to assume responsibility for many of the fundamental research objectives of germplasm management described in phases 1 through 4. On the contrary, the research efforts of industry have been and are likely to continue to be concentrated in those areas of practical plant breeding designed to produce the maximum number of commercially acceptable cultivars in a minimum amount of time. In providing answers to fundamental breeding questions, increased support of the public research institutions is essential.

The cooperation between the public institutions engaged in the genetic manipulation of plant germplasm and the private seed industry is unique to the United States. Over the years, the two groups have arrived voluntarily at a logical division of labor that includes minimal duplication of effort. The complementary nature of the relationship has served American agriculture well. The need for this kind of cooperation is as great today as at any time in the past. Each crop improvement program of industry and the public agencies does not need all seven phases; the Nation needs all eight phases. The program can be a model for the national sharing of the workload among State and Federal agencies and private industry.

Phase 8 **Produce a reliable quantity of high-quality food, plant products, and specialty plants for the consumer.**

This is the final phase of plant germplasm use. The American farmer has been eminently successful in producing an abundance of a wide array of high-quality foodstuffs and plant products at a low cost to the consumer. In addition, significant quantities of grain and other agricultural commodities have been exported to make an impressive impact on foreign trade.

PLANT BREEDING: A RESEARCH PRIORITY

Classical plant breeding continues to be highly successful in the improvement of field, horticultural, and tree crops. Throughout history the practitioners of plant breeding technology have shown flexibility in utilizing new tools that contribute to plant improvement. In so doing, those programs and disciplines that relate to plant improvement have served agriculture and thus the nations around the world exceptionally well.

The broad field of genetic engineering and other recent technologies are among those new tools now available to the breeder to complement conventional methods. Continuing progress in improving the performance of crop plants at a given point in time will be accomplished by the integration of new technologies with the conventional methods.

The following are examples of what can be accomplished through research in plant breeding:

Pest control by genetic means.--Through the years agriculture has depended largely upon the use of chemical pesticides to control most insects, diseases, and weeds. The system has been reasonably effective, but the effects of some of the more persistent chemicals on the environment and the presence of genetic resistance by pests to pesticides now have become a matter of national concern. One of the safest alternatives to the chemical control of pests is the development and use of genetically resistant cultivars. These cultivars are developed primarily by conventional breeding techniques. Sources of resistance often are available within adapted germplasm but also are found frequently in "exotic" varieties, i.e., in nonadapted varieties or those grown only in other parts of the world. Examples of the successful use of exotic germplasm are greenbug resistance in sorghum, Hessian fly resistance in wheat, aphid resistance in alfalfa, mosaic resistance in tomatoes, anthracnose and head smut resistance in sorghum derived from tropical sorghums of Africa, and resistance to corn leaf blights from materials introduced from Central and South America. Sources of resistance to many pests of fruit and vegetable crops came from plant introductions.

Food quality and safety.--Most plant breeding has been directed toward the improvement of yielding ability and other agronomic and horticultural traits that affect yields either directly or indirectly. Increased attention needs to be given to nutritive quality and food safety by screening and evaluating a much broader range of germplasm than is present in the normal stocks of materials with which breeders work. Expanded research in the area of food quality and safety is an integral part of the program recommended in this document.

Increase in genetic diversity and plant productivity.-- The farmer, processor, distributor, and consumer demand uniformity in crop varieties and food products. Plant breeders have met these demands for uniformity, but in so doing have decreased the genetic diversity of varieties of many of the Nation's major crop species. Unfortunately, a decrease in genetic diversity is frequently accompanied by an increase in genetic vulnerability to economic loss caused by some new pathogen, insect pest, or unusual environmental stress. It is imperative, therefore, that attempts be made to restore a measure of genetic diversity through the use of new and unrelated sources of germplasm in plant breeding programs.

The conservation and use of plant genetic resources through the application of classical plant genetics and breeding, as shared among State, Federal, and industry organizations, continues to be a cost-effective investment of public and corporate funds. The new technology of genetic engineering has the potential to be used to transfer agriculturally important genes among plant species not now possible by conventional techniques.

CROP ADVISORY COMMITTEES

During recent years, sizable resources have been directed to support the improvement of the major food commodities worldwide. Support of a network of international agricultural research institutes has increased substantially in recent decades. Concurrently, a number of national agricultural research systems have been strengthened at an annual cost several times that invested in the international institutes. Most international agricultural research is organized around commodities. For the United States to be informed about developments abroad, we should have strong crop commodity committees comprising authorities in plant breeding, plant pathology, entomology, and other relevant fields.

The United States should maintain a cadre of national and international commodity experts in ARS, SAES, and private industry to keep the Nation at the forefront of national and international efforts.

There should be a separate national crop advisory committee for each crop or group of crops of significance to American agriculture. ARS, SAES, or private industry could provide leadership and support. In most cases the committee leader should be a plant breeder or geneticist of high national standing. Representation on each committee should include all relevant disciplines, if possible. Each committee should--

- Develop a strategic overview of progress in the United States with each crop commodity, identifying strengths and weaknesses of the national scientific efforts on improving that species, and recommend means of organizing activities that would benefit from national cooperative work. Particular attention should be given to plant breeding and genetics, and to activities on disease and insect resistance, quality, and enhanced plant productivity.

- Develop an ever-improving understanding of foreign scientific developments on the crop in question, identifying and describing implications for science and agriculture in the United States.

- Provide periodic reports on national and international developments with the species, with statements of implications for the United States and recommendations for strengthening work, either in this country or in institutions abroad receiving major support from this country.

- Assess the adequacy of the germplasm base for each crop or group of crops and make recommendations to the curators, NPGC, and NPGRB for broadening and strengthening each base by additional exploration, evaluation, and/or enhancement work.

- Develop guidelines for improving the effectiveness of germplasm collection, evaluation, maintenance, increase, and regeneration on any and all crops. The guidelines should address such questions as (1) What is the best procedure for increasing original collections of cross-pollinated grasses? (2) How does one handle germplasm of valuable forest tree species? or (3) How should special germplasm collections be saved when the curator retires or dies or the program is dropped?

- Cooperate with the respective commodity research groups, such as the National Alfalfa Improvement Conference, National Oat Conference, and Sorghum Improvement Conference of North America, and represent them as an action committee on germplasm concerns.

- Assess the impact of genetic engineering and other biotechnologies on germplasm resource needs and developments in their respective crops.

PERSONNEL REQUIREMENTS

The NPGRB recognizes the expanding need for competent scientists broadly trained in germplasm resources management to meet the needs for maintenance of plant germplasm collections and germplasm research. The Board encourages universities to provide strong training in plant biology, including genetics, taxonomy, genetic engineering, evolution, and other related disciplines.

NPGRB AND ITS RESPONSIBILITIES

The NPGRB has responsibility to--

- Advise the Secretary of Agriculture on broad policy issues relating to all aspects of germplasm resources and make recommendations for their effective use in crop improvement.

- Continually evaluate the NPGS and make recommendations for increasing its effectiveness.

- Identify plant germplasm research areas in need of funding.

1. **Continue to improve the U.S. National Plant Germplasm System**

   Recognize that the eight-phase program presented in this document is an outstanding example of State, Federal, and industry coordination and cooperation for the achievement of the common national goals that have a high priority.

   - Recognize that plant breeding, using established and innovative methods, should be given high research priority.

   - Recognize that plants developed by recombinant DNA technology/genetic engineering and other biotechnologies must be integrated into plant breeding and production programs before agricultural benefits are fully realized.

   Support ARS and SAES in the following ongoing programs recommended by the NPGC:

   - Strengthen international cooperation.

   - Construct and operate a system of clonal repositories for fruit and nut crop germplasm.

   - Refine and expand the germplasm information system.

   - Perform research on the enhancement and use of germplasm through traditional and molecular techniques.

2. **Recognize the preeminence of U.S. Crop Advisory Committees (CAC's)**

   Use existing CAC's composed of genetic resource experts on each important crop (or groups of crops where that seems desirable) as follows:

   - Monitor germplasm collections and breeding progress of other national and/or international agricultural research institutes.

   - Make specific recommendations on plant introductions and explorations.

   - Recommend procedures and responsibilities for maintaining and using plant germplasm.

   - Suggest research programs to make maximum use of germplasm resources for the benefit of producers and consumers in the United States.

- Make periodic reports on the state of efforts in the United States and the world to improve productivity of the species or to develop materials for potential world markets.

3. **Support Programs for Genetic Improvement of Cultivated Crops**

   Assign high priority both to germplasm enhancement and to understanding the genetic systems of each important crop species.

   - Promote the establishment of crop enhancement teams with at least one plant breeder, pathologist, and entomologist on each team. Most teams also should have a geneticist, cytogeneticist, biochemist, physiologist, or soil scientist.

   - Provide resources to rapidly and economically evaluate characteristics important in food safety, nutrition, pest resistance, and product quality.

   - Conduct research on the technology of evaluating materials for pest resistance, tolerance to environmental stresses, and quality enhancement.

   - Ensure that available funds are flexible and permit rapid expansion or redirection when new disease, insect, or stress problems arise. A strong backup program is necessary to offset widely used single forms of pest resistance that may be of short duration in major crop cultivars.

   - Support and promote basic studies in genetics, cytogenetics, genetic engineering, and other fields that contribute to an understanding of the genetic makeup of each significant crop species and its interspecific relationships.